2008 Gulf of Alaska Walleye Pollock Year-Class Prediction: <u>Average Recruitment</u>

26 September 2008

DATA

This forecast is based on five information sources: three physical properties and two biological data sets. The information sources are:

1. Kodiak total monthly precipitation.(inches) prepared by the Kodiak National Weather Service office (http://padq.arh.noaa.gov/) from hourly observations. Data for 2008 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

2. Wind mixing energy at [57°N, 156°W] estimated from sea-level pressure analyses for 2008. Monthly estimates of wind mixing energy (W m^{-2}) were computed for a location near the southwestern end of Shelikof Strait. To make the estimates, twice-daily gradient winds were computed for that location using the METLIB utility (Macklin *et al.*, 1984). Gradient winds were converted to surface winds using an empirical formula based on Macklin *et al.* (1993). Estimates of wind mixing energy were computed using constant air density (1.293 kg m^{-3}) and the drag coefficient formulation of Large and Pond (1982).

3. Advection of ocean water near Shelikof Strait inferred from wind and transport data during the spring of 2008.

4. Rough estimates of pollock larvae abundance from a survey conducted in late May 2008.

5. Estimates of age-2 pollock abundance and spawner biomass from the 2008 assessment.

ANALYSIS

Kodiak Precipitation: Kodiak precipitation is a proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock.

It was a year of extremes. The season began with drying in January, followed by wetter than normal (30-year mean) conditions through March (Table 1). This increased the potential for formation of baroclinic instabilities prior to and during spawning. April was relatively dry, however the later spring months brought record rain, with May 2008 being the all-time wettest May. The spring may have presented favorable eddy habitat for late larval- and early juvenile-stage walleye pollock, although one might question the contribution of such extreme rain to favorable larval survival.

TABLE 1. Kodiak precipitation for 2008.

Month	% 30-yr average
Jan	58
Feb	161
Mar	174
Apr	54
May	267
June	147

Based on this information, the forecast element for Kodiak 2008 rainfall has a score of 2.49. This is "average to strong" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and "strong" using three categories.

Wind Mixing: Wind mixing at the southern end of Shelikof Strait was below the long-term average for five of the first six months of 2008 (Table 2).

TABLE 2. Wind mixing at the exit of Shelikof Strait for 2008.

Month	% 30-yr average
Jan	67
Feb	64
Mar	44
Apr	81
May	105
June	50

Strong mixing in winter helps transport nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak spring mixing is thought to better enable first-feeding pollock larvae to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This year's scenario produced a wind mixing score of 1.97, which equates to "average" on 3- and 5-category scales.

Winds and Transport in the Alaska Coastal Current: There were very limited direct oceanographic measurements of transport during 2008, but transport in Shelikof Strait is well correlated with the along-shore winds. An examination of the atmospheric pressure patterns and available wind data indicates that wind forcing in spring 2008 was average. This supports the few direct observations taken. Thus, the prediction is that transport was average for 2008. Very strong transport tends to remove larvae from the sea valley and is often associated with poor year classes. Weak to moderate transport after hatching is necessary (but not sufficient) to support an above- average year class.

Based on these observations, the 2008 pollock year-class prediction from transport information would indicate an average year class. We give this element a score of 2.0, which equates to average.

Relating the Larval Index to Recruitment*:* As in previous analyses, a nonlinear neural network model with one input neuron (larval abundance), three hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (CPUA, average catch, m^{-2}) to age-2 recruitment abundance (billions). The model estimated eight weighting parameters.

The neural network model, which used the 22 observation pairs of Table 3 to fit the model, had a very low R^2 of 0.041. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) is given in Fig. 1, where row number corresponds to the rows of the data matrix given in Table 3 and thus indicates year class.

TABLE 3. Data used in the neural network model.

| Year Class	Mean CPUA	Recruit
1982	71.14	0.212121
1985	80.42	0.562104
1987	329.74	0.381159
1988	260.21	1.64472
1989	537.29	1.02849
1990	335	0.411432
1991	54.22	0.245024
1992	562.79	0.149022
1993	185.34	0.226235
1994	126.58	0.880295
1995	610.33	0.422492
1996	477.69	0.180603
1997	568.42	0.164458
1998	72.2	0.223236
1999	96.14	0.857654
2000	492.04	0.746177
2001	171.3	0.110101
2002	175.64	0.096409
2003	135.36	0.100795
2004	21.22	0.528081
2005	76.22	0.502001
2006	327.69	0.693409
2007	71.15	
2008	111.83	
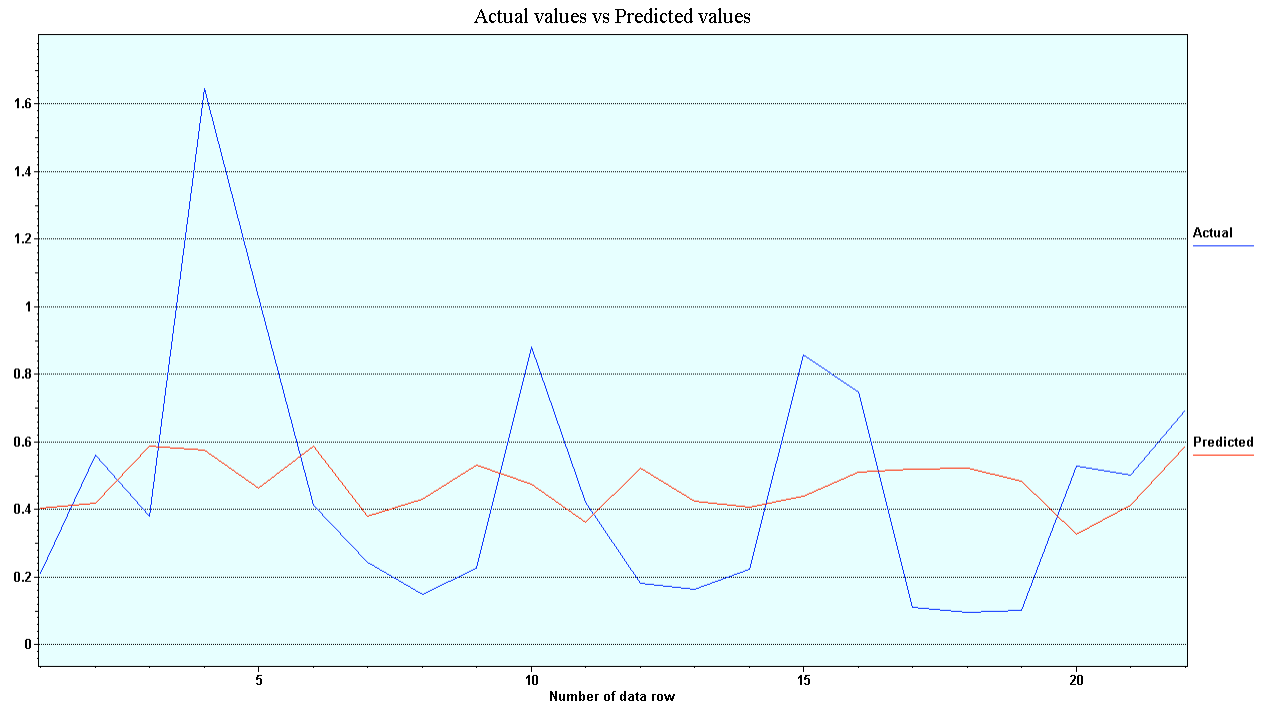
FIGURE 1. Observed and predicted recruitment values from the larval index-recruitment neural network model.

The trained network was then used to predict the recruitment for 2006 and 2007. The predictions are given in Table 4.

TABLE 4. Neural network model predictions for 2006 and 2007.

Year	Actual Recruitment	Predicted Recruitment
2006	n/a	0.430
2007	n/a	0.458

These values, using the 33% (0.3579) and 66% (0.7011) cutoff points given below, correspond to an average 2006 year class and an average 2007 year class or a score of 2.0.

Larval Index Counts: Plotting the larval abundance data by year and binning the data into catch/10 m^2 categories (given below) provides another view of the data. The pattern for 2008 (based on rough counts) differs from last year in that the frequency distribution is skewed towards lower binning categories (Figure 2). These patterns indicate that the 2008 year class may be average because, in general, other years with low binning categories correspond to average recruitment.
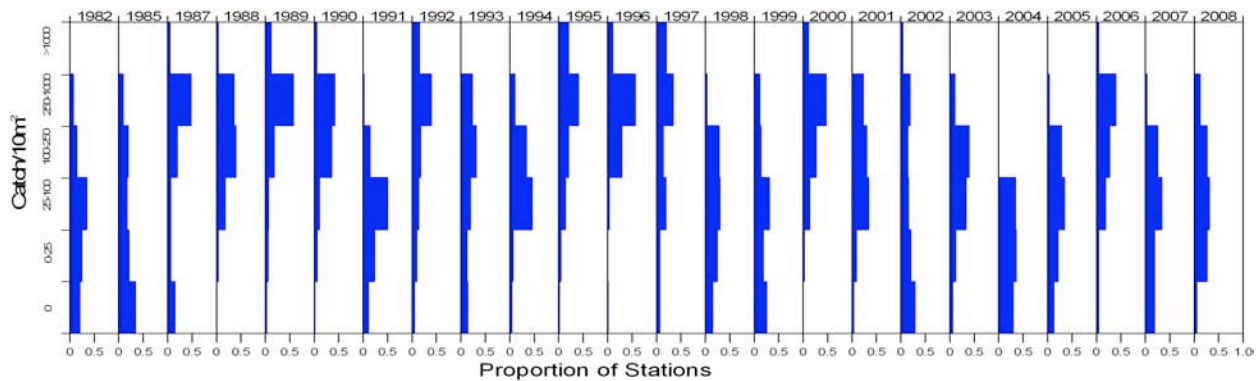
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FIGURE 2. A series of histograms for larval walleye pollock densities in late May from 1982 to 2008. Data were binned into catch/10 m² categories. The data from 2000-2006 are actual verified larval counts, 2007 are unverified counts from the Polish Plankton Sorting Institute, and 2008 data are rough counts from the 4DYF08 FRV *Oscar Dyson* survey cruise that was completed in late May.

The data for Figures 3-7 are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock (Fig. 7) appears to be centered in the typical reference area, and the spatial pattern is similar compared to previous years. The larval abundance figures in the middle of the reference of Figure 7 seem to be average. Comparing the catch rates (Fig. 2) shows that the 2008 rough counts seem to be distributed to middle to high values compared to 2007, and the distribution of larvae in 2008 (Fig. 7) compared to last year (Fig. 6) was spatially similar. Given these two pieces of information, the score for larval index is set to the high end of average or 2.33.
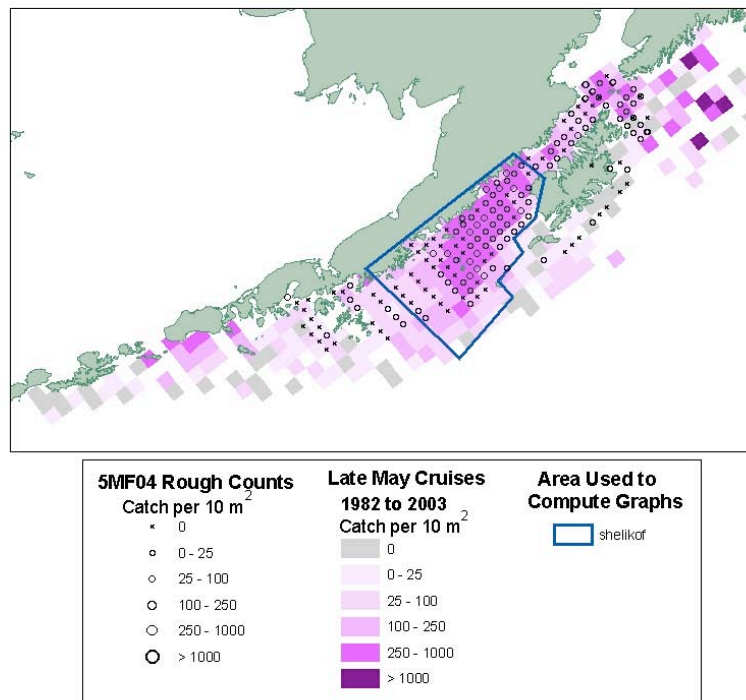

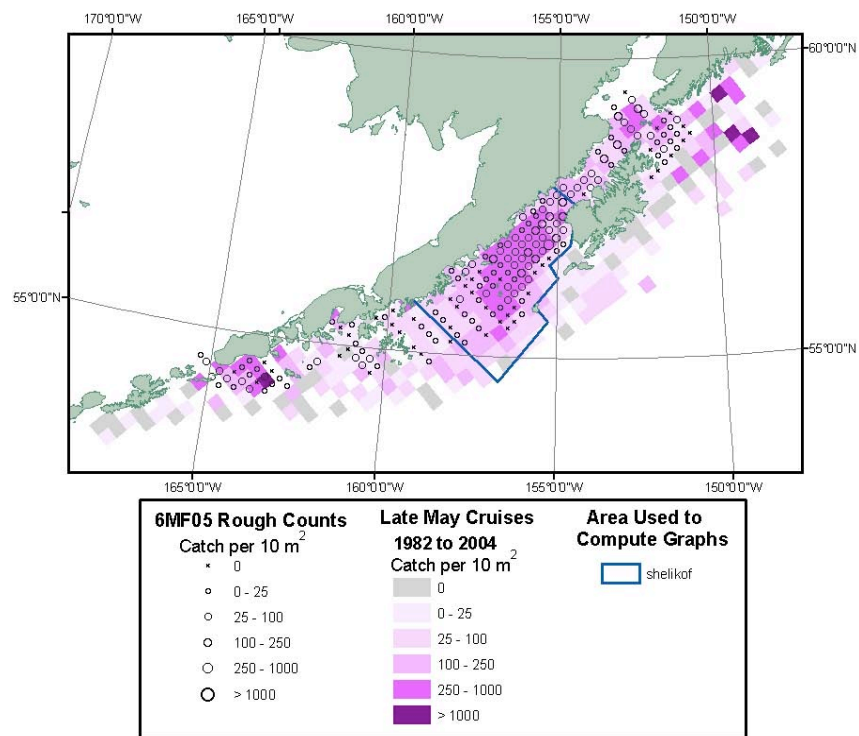**FIGURE 3. Mean catch per 10 m² for late May cruises during 1982-2003, with observed rough counts overlaid for 2004.**

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FIGURE 4. Mean catch per 10 m^2 for late May cruises during 1982-2004, with observed rough counts overlaid for 2005.

FIGURE 5. Mean catch per 10 m^2 for late May cruises during 1982-2005, with observed rough counts overlaid for 2006.

FIGURE 6. Mean catch per 10 m² for late May cruises during 1982-2006, with observed rough counts overlaid for 2007.
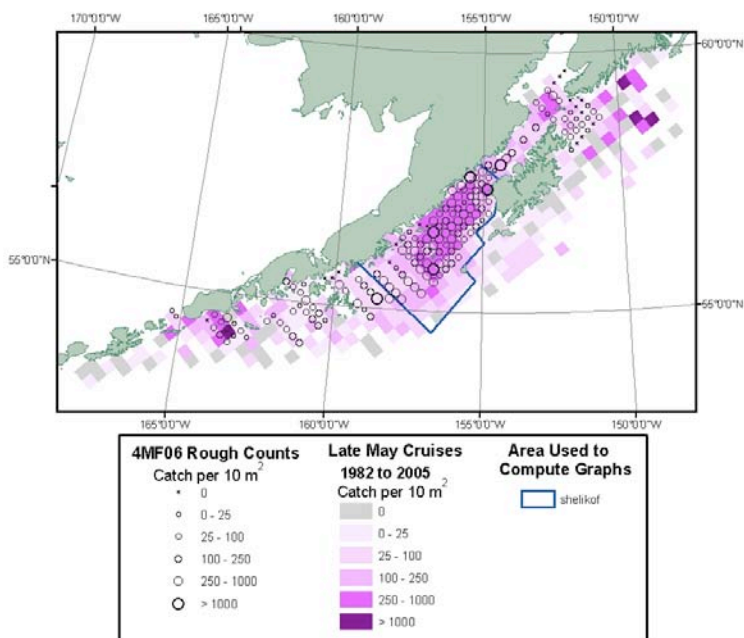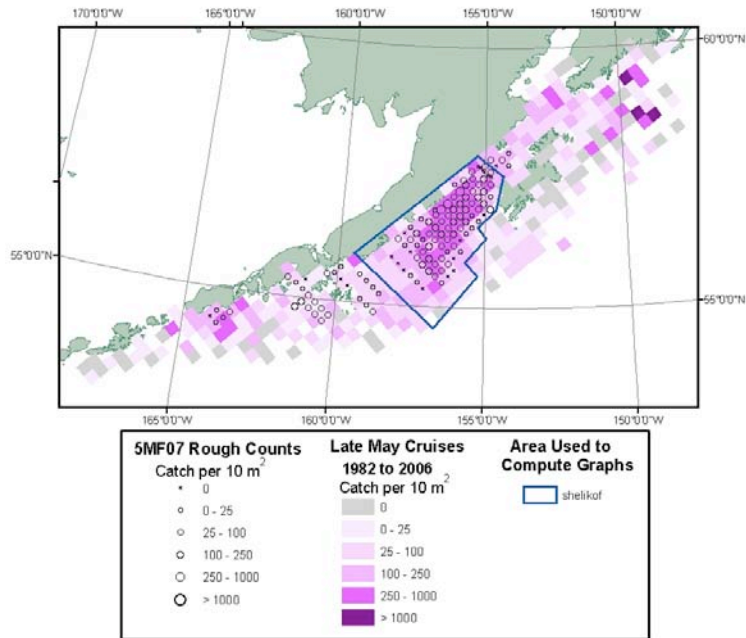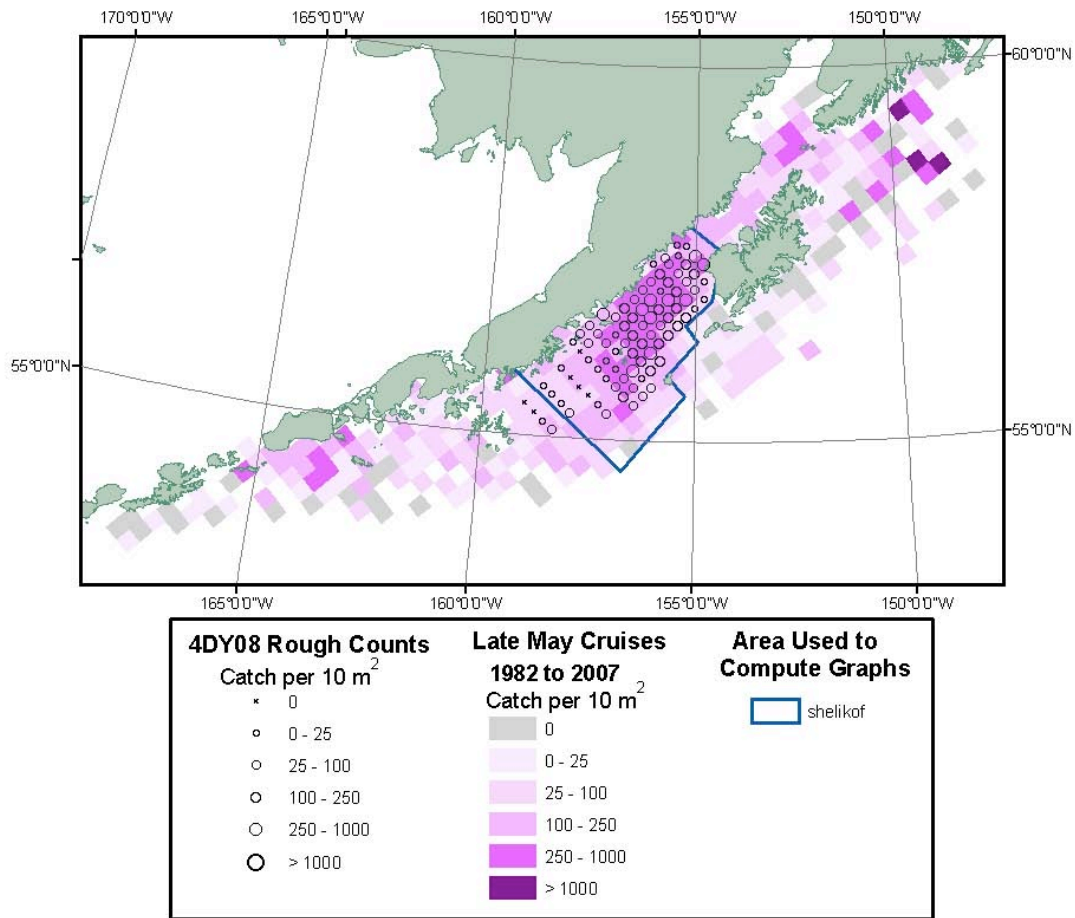
FIGURE 7. Mean catch per 10 m² for late May cruises during 1982-2007, with observed rough counts overlaid for 2008.

Recruitment Time Series: The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition in time. The data set consisted of age-2 pollock abundance estimates from 1961-2008, representing the 1959-2006 year classes. There were a total of 48 recruitment data points. The 33% (0.3579 billion) and 66% (0.7011 billion) percentile cutoff points were calculated from the full time series and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated:

1. Probability of a weak year class following a weak
2. Probability of a weak year class following an average
3. Probability of a weak year class following a strong
4. Probability of an average year class following a weak
5. Probability of an average year class following an average

6. Probability of an average year class following a strong
7. Probability of a strong year class following a weak
8. Probability of a strong year class following an average
9. Probability of a strong year class following a strong

The probabilities were calculated with a time lag of two years so that the 2008 year class could be predicted from the size of the 2006 year class. The 2006 year class was estimated to be 0.6934 billion and was classified as average. The probabilities of other recruitment states following an average year class for a lag of 2 years (n=48) are given below:

TABLE 5. Probability of the 2007 year class being weak, average and strong following an average 2005 year class.

2008 Year Class		2006 Year Class	Probability	N
Weak	Follows	Average	0.1304	6
Average	Follows	Average	0.1087	5
Strong	Follows	Average	0.0652	3

The probability was highest for a weak year class following an average year class and was similar to an average following an average. We classified this data element to be in the weak category but toward the higher end of the range, giving it a score of 1.66.

Spawner/Recruit Time Series*:* The data from the previous analysis only looked at the time sequence of the recruitment data points. This section looks at both the recruitment (R) and the spawning biomass (SB) in the context of transition probabilities after Rothschild and Mullin (1985). The benefit is that it is non-parametric, and it provides a way to predict recruitment without applying a presumed functional spawner-recruit relationship. It involves partitioning the spawning stock into N-tiles and the recruitment into N-tiles, classifying the stock into NxN states. We used the 50% percentile of the data to calculate the median spawning biomass (0.2241 million tons) and recruitment (0.4495 billion). These values were used to partition the spawner-recruit space into 4 states. State 1:low SB-low R, state 2:low SB-high R, state 3:high SB-low R, and state 4:high SB-high R. These areas correspond to the lower left, upper left, lower right, and upper right quadrants of the lower panel in Figure 8. The classification then makes it possible to study the probability of any state and the transitions between the states.

The time series of recruitment data and the 2x2 spawning biomass-recruitment plot are shown in Figure 8.
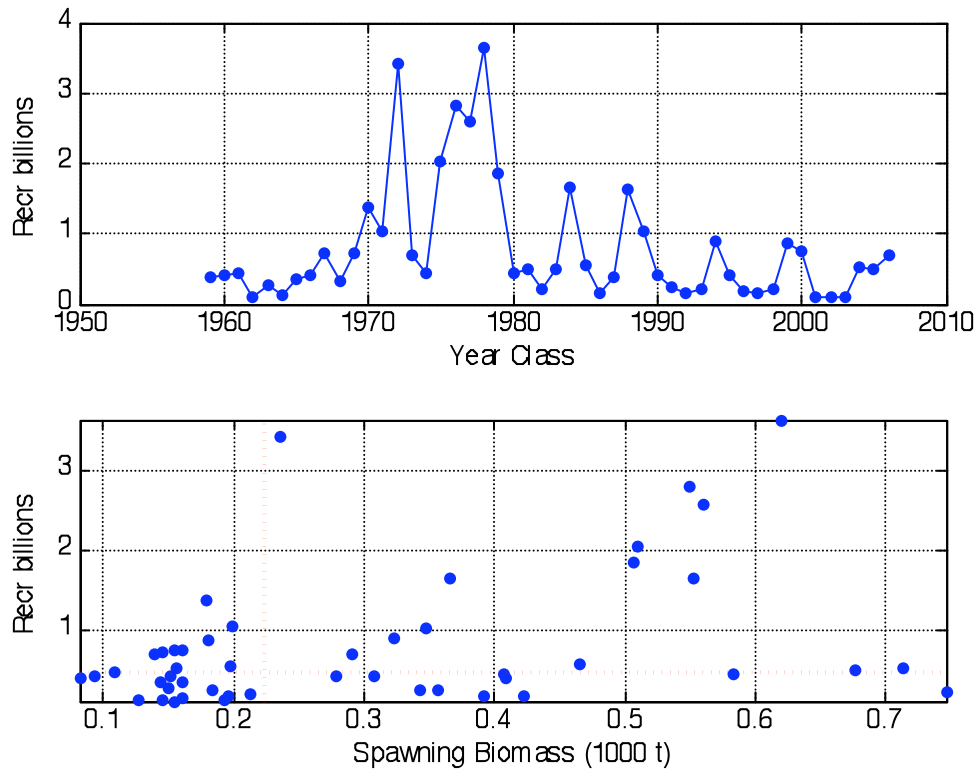
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FIGURE 8. Time series of recruitment and the 2x2 classification of the 2008 spawning biomass and recruitment data.

TABLE 6. Transition matrix calculated from data in Figure 8.

Transition Probability Matrix	To state 1	To state 2	To state 3	To state 4
From state 1	0.6429	0.3571	0.0000	0.0000
From state 2	0.3333	0.5556	0.0000	0.1111
From state 3	0.1000	0.0000	0.4000	0.5000
From state 4	0.0000	0.0000	0.4286	0.5714

To calculate the score from Figure 8 takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2007 (0.15586 million tons) and note that it falls below the median value of 0.2241. We can see that in 2007 we are in either state 1 or state 2 (low spawning biomass). The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of Table 6.

If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above (a recruitment score of 3) the median of 0.4495 billion (a recruitment score of 2). Note the probability for transitioning from state 1 to state 3 or 4 is 0.0. If we start in state 1, then the combined recruitment score would be the weighted average of the recruitment scores for each

possible transition, where the weighting factors are the transition probabilities. So, the calculations for the second step proceed as described below.

The weighted recruitment score (given we start in state 1) is the recruitment score for staying in state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 1 back to state 1) plus the recruitment score for transitioning from state 1 to state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 1 to state 2), all divided by the sum of the weights.

$$= \frac{(1 * 0.6429) + (3 * 0.3571)}{(0.6429 + 0.3571)} = 1.714$$

Similarly, the weighted recruitment score (given we start in state 2) is the recruitment score for staying in state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 back to state 2) plus the recruitment score for transitioning from state 2 to state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 2 to state 1), plus the recruitment score for transitioning from state 2 to state 4 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 to state 4), all divided by the sum of the weights.

$$= \frac{(3 * 0.5556) + (1 * 0.3333) + (3 * 0.1111)}{(0.5556 + 0.3333 + 0.1111)} = 2.33$$

We average over these two weighted scores because starting from either state 1 or state 2 is equally likely if the starting spawning biomass in 2007 is below the median, giving a final score of 2.02, or average.

One final calculation possible from these data is the expected first passage time or the number of years on average that a stock and recruitment system in a particular state will take to return to a particular state. These data are given in Table 7. For example, it would take 8.0 years for Gulf of Alaska pollock in State 2 to return to State 1.

<center>TABLE 7. Expected First Passage Time.</center>

State	1	2	3	4
1	3.9464	2.8000	22.5333	20.2000
2	8.2500	4.9111	19.7333	17.4000
3	21.6667	24.4667	4.4200	5.0333
4	24.0000	26.8000	2.3333	3.1571

CONCLUSION

The larval index data element was weighted low (0.1) because the recruitment variability explained by larval abundance was very low. All the remaining elements were weighted equally.

Based on these seven elements and the weights assigned in Table 8, below, the FOCI forecast of the 2008 year class is average.

TABLE 8. Final 2008 pollock recruitment forecast.

Element	Weights	Score	Total
Rain	0.15	2.49	0.37
Wind Mixing	0.15	1.97	0.30
Advection	0.15	2.00	0.30
Larval Index-abundance	0.10	2.00	0.20
Larval Rough Counts and Distribution	0.15	2.33	0.35
Time Sequence of R	0.15	1.66	0.25
Spawner-Recruit Time Series	0.15	2.02	0.30
Total	**1.00**		**2.07= Average**

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